



Biomass Sources, Characteristics, Challenges, and Opportunities

Bruce E. Rittmann

Director, Swette Center for Environmental Biotechnology
Biodesign Institute at Arizona State University

Regents' Professor, School of Sustainable Engineering and
the Built Environment
Ira A. Fulton Schools of Engineering



Tonight's Itinerary

Context

Biomass Sources and Characteristics

Challenges

Opportunities



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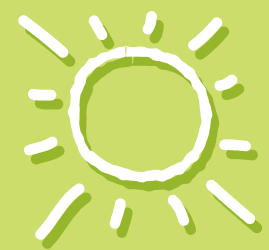
Scale! Scale! Scale! Scale!

- Human activities now use energy at a rate of ~ 17 TerraWatts (TW = a trillion watts = 10-billion 100-watt light bulbs).
 - $\sim 84\%$ is from fossil fuels (~ 14 TW): 34% oil, 32% coal, 14% natural gas
- Thus, C-neutral sources must work on a very large scale to be of significant value towards the goal of replacing fossil fuels.
- To hold today's CO_2 concentration (~ 400 ppm), we need to cut fossil fuel use to ~ 4 TW over the long term.

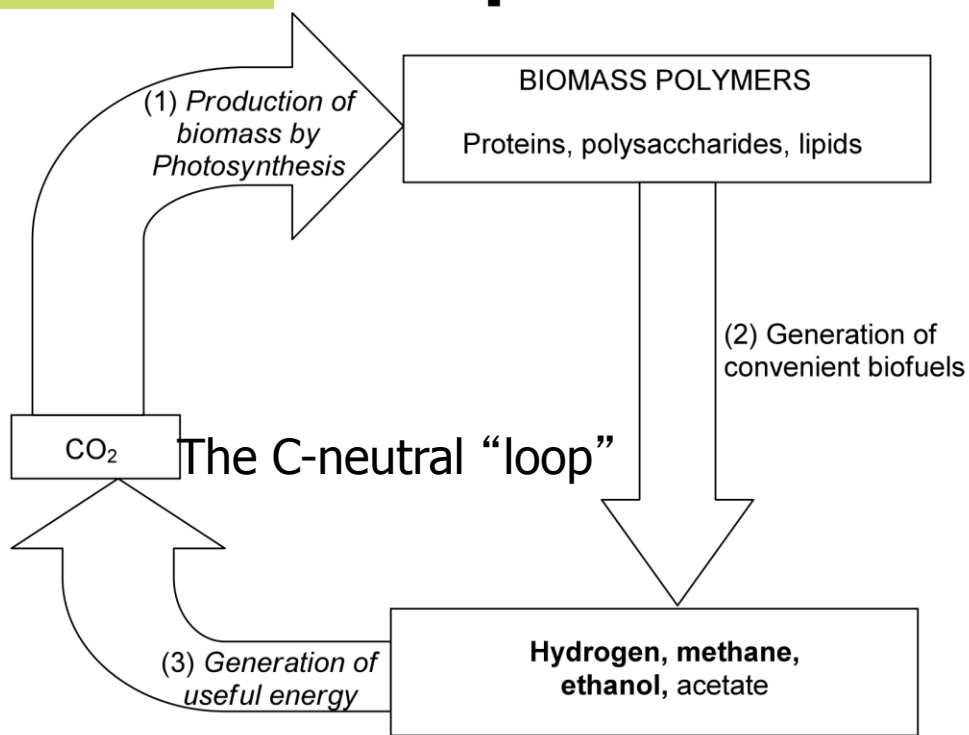


Scale! Scale! Scale! Scale!

- Human Fossil-Energy Use Rate: ~ 14 TW
- Sunlight hitting the Earth's surface: 173,000 TW
 - More than 10,000 times what we use
 - Here is the upside potential
- Sunlight energy captured as all biomass: ~ 140 TW
 - Only ~ 10 times more than we use for all human energy use
 - Here lies the heart of the scale problem today: Human society demands more energy than is routinely and safely provided by natural photosynthesis.
 - Thus, we mine stored up energy in fossil fuels.



The Principle For C-Neutral Bioenergy



1. Solar energy is captured by photosynthesis into biomass and takes up CO₂. The electrons come from H₂O.
2. Some biomass can be used directly as a bio-fuel, such as wood. Most biomass is converted into other useful forms that are.....
3. Converted to useful energy for electricity, heating.

The generation steps return CO₂ to the biosphere → C neutral!



Comparison to Fossil Fuels

- It is the same principle for fossil fuels: photosynthesis to yield biomass.
- The difference is that the fossil fuels were produced and accumulated over 100s of millions of years, while
- Humans are mining and combusting the accumulation in just a few 100 years!



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Residual Biomass Sources Are Significant

- If all residual biomass from agriculture and human activities could be collected and converted into useful energy, this would meet $\sim 25\%$ of the societal demand worldwide.
- Thus, residual biomass could “make a real dent” in meeting energy demand if converted to “biocrude,” methane, hydrogen, or electricity.



How much residual biomass do we have?

Acknowledgement: Dr. Prathap
Parameswan, now an assistant
professor at Kansas State University



Major Sources	Million Dry Tons Per Year (USA)	Percent
Animal Wastes	335	55
Food Processing	113	19
Pulp and Paper	149	25
Municipal Wastewater	7	1
Total	604	100



Large and readily biodegradable

Major Sources	Million Dry Tons Per Year (USA)	Percent
Animal Wastes	335	55
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Municipal Wastewater	7	1
Total	604	100



Animal Wastes

Animal Type	Amount, millions dry tons per year	Percentage of all Biomass
Cattle	253	42
Swine	31	5
Poultry	51	8
Total	335	55

Only about 3.6 million tons per year is subject to energy recovery today.



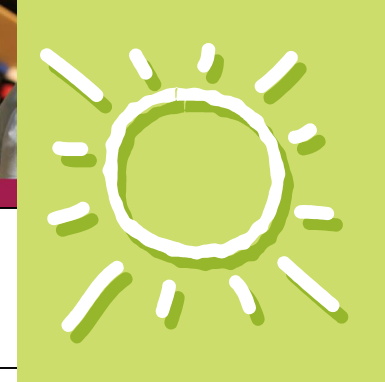
Major Sources	Million Dry Tons Per Year (USA)	Percent
Animal Wastes	335	55
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Total	604	100

< 10% of USA energy use today.



So, residual biomass truly is not enough!

- If all biomass sources could be collected and converted into useful energy, this would meet $\sim 25\%$ of the total worldwide energy demand today; $\sim 7\%$ in the USA.
- We need to do a lot more photosynthesis, but in an environmentally acceptable manner to make up the difference.

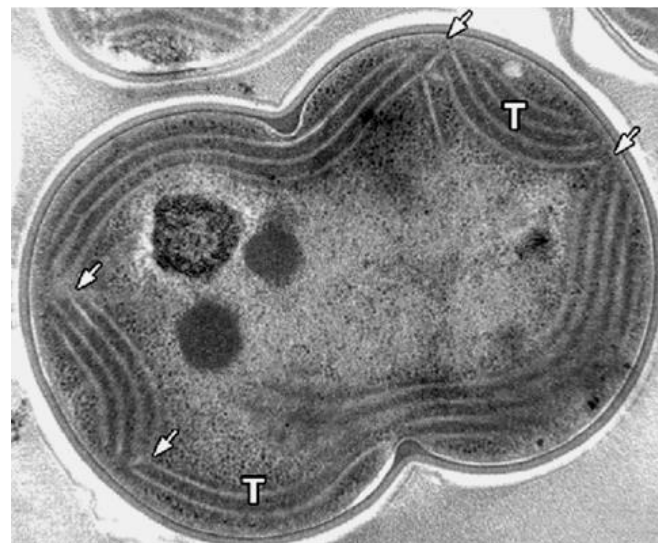


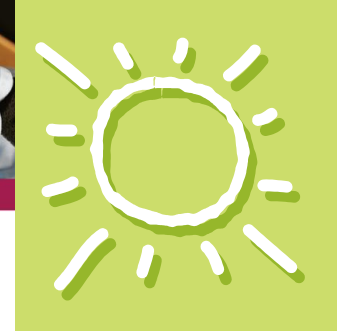
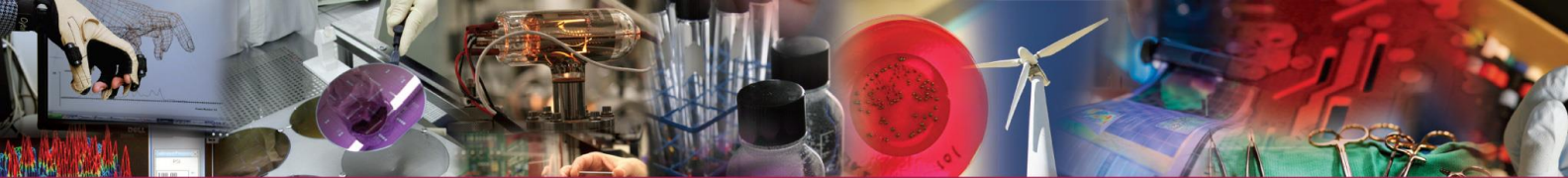
Plants or Microbes?

Traditional Biomass/Biofuel
Production Focus: Plants



Microorganisms:
photosynthetic algae and
bacteria





Plants or Microbes?

Plants

- Slow growing - usually only one crop a year
- Require arable land
- Growth seasonal
- Low areal production:
- Heterogeneous (leaves, seeds, stems, etc.)
- Require water and fertilizer
- Largely lignocellulosic

Photosynthetic Microorganisms

- Fast growing - doubling time 0.5-1 day
- Do not require arable land
- Growth year-round
- High areal production (see table)
- Homogeneous (all cells are the same)
- Water-efficient; reuses minerals
- Not lignocellulosic

Organism	Lipid production ($L_{na}^{-1} yr^{-1}$)
Photosynthetic Microbes	72,000-130,000
Sunflowers	570-1,000
Soybeans	380-650

Adapted from Huber GW, Iborra, S., Corma, A.
 Synthesis of transportation fuels from biomass:
 Chemistry, catalysts, and engineering. *Chem Rev* 106
 (2006) 4044-4098



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Key characteristics of the biomass?

- It is a mixture of polymers of carbohydrates, proteins, and lipids.
- It is wet.
- Anything not used is pollution!



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Viable Options

Anaerobic Biodegradation to CH_4 ,
 H_2 , or electrical power

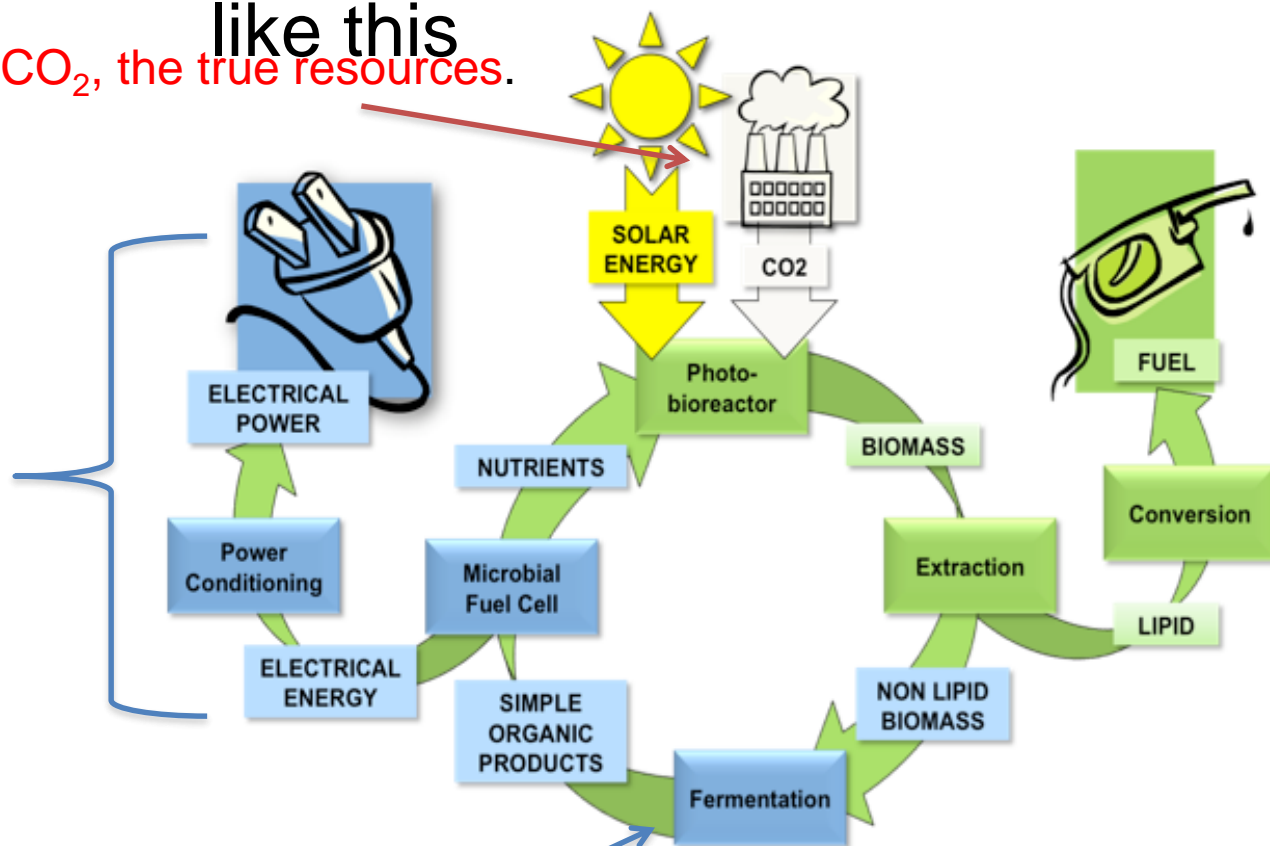
HydroThermal Liquifaction to
“biocrude”



An integrated photobioenergy system will look like this

Inputs are sunlight and CO₂, the true resources.

The left side could be, instead of an MFC for electricity, an MEC for H₂, anaerobic digestion for CH₄, or some combination



Any type of biomass can enter the system here



HydroThermal Liquifaction (HTL)

A thermal depolymerization process used to convert wet biomass into crude-like oil – “biocrude” – under moderate temperature (250 - 550 C) an high pressure (5 – 25 mPa).

The biocrude has a high energy density with a lower heating value around 35 MJ/kg and 5 – 20 wt% O.



Summary

- We must have renewable, C-neutral alternatives on a very large scale -- TWs.
- Residual biomass today has a lot of energy, and massively growing photosynthetic microorganisms can help biomass meet the TW test without introducing massive environmental and social problems.



Summary

- We must capture all of the energy in carbohydrates, proteins, and lipids.
- Anaerobic biodegradation to form CH_4 , H_2 , or electrical power, perhaps integrated with lipid extraction.
- Hydrothermal liquifaction to “biocrude.”



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Methane

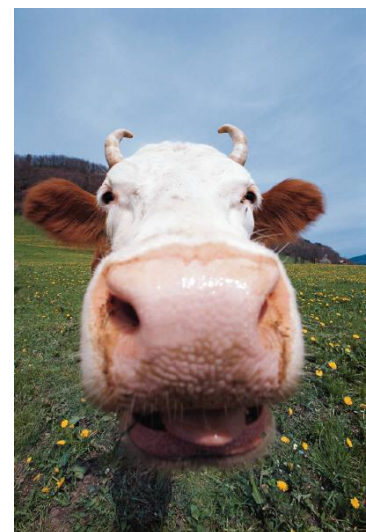
- CH_4 has 8 e^- equivalents per mole.
 - $\text{CO}_2 + 8\text{H}^+ + 8\text{e}^- \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$
- CH_4 is **natural gas**, already widely used for heating and producing electricity.
- CH_4 is C-neutral only if it comes from biomass, not from fossil fuel!
- Biomass can be photosynthetic microorganisms, agriculture/food residues, sewage sludge.....

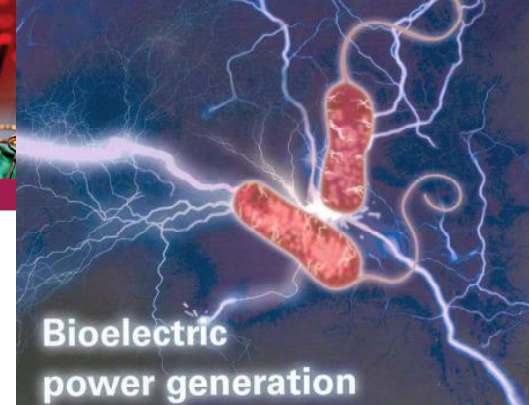




Methane

- Methanogenesis has a long history (over 160 years) and is a proven technology.
- The main drawbacks today are
 - The fraction of energy value converted to CH_4 is not high enough from complex biomass.
 - The unit cost is relatively high compared to fossil-fuel natural gas.
- The first drawback may be eliminated in the not-so-distant future by technology advances in pre-treatment.





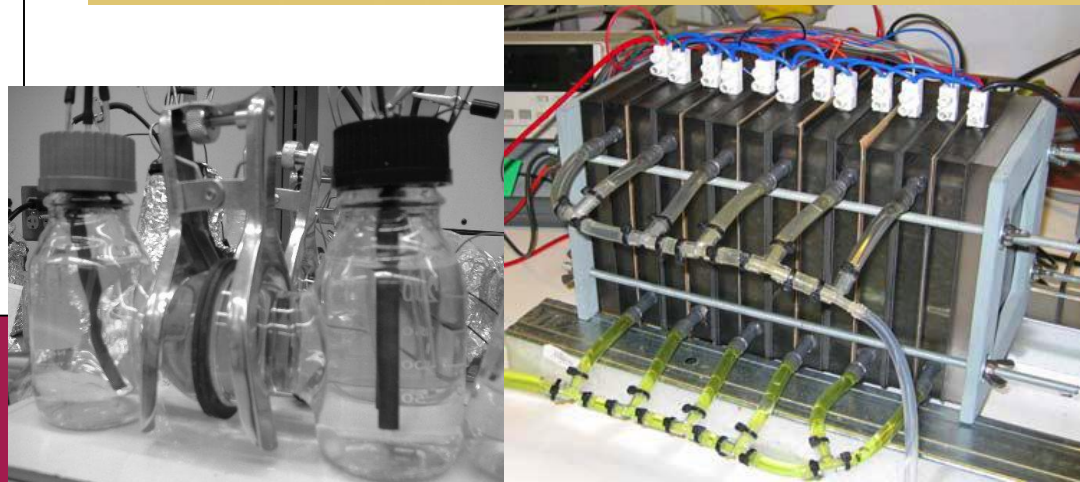
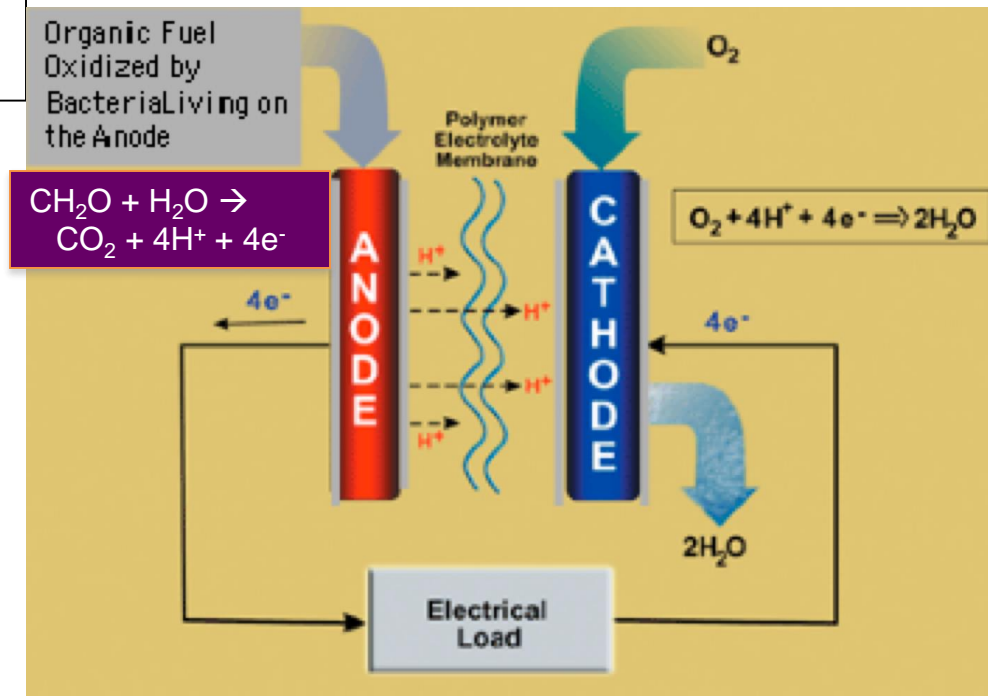
Bio-Electricity

- A microbial fuel cell (MFC) can capture the energy in organic “fuel” directly as electrical energy, or the electrons (e^-) themselves.
 - $\text{CH}_2\text{O} + \text{H}_2\text{O} \rightarrow 4\text{H}^+ + 4e^- + \text{CO}_2$
- A biofilm of anode-respiring bacteria (ARB) oxidizes the organics (BOD) in wastes and transfers them to the anode of a fuel cell.
- This is combustionless, pollution-free electricity. And, it also can solve a BOD-waste problem at the same time.



Microbial Fuel Cells

- Bacteria living as a biofilm on an electrode remove electrons from an organic fuel and transfer them to the electrode and through the circuit to harvest electrical energy, or bio-electricity.
- Thus, fuel-cell technology can use renewable organic fuels from wastes and fuel crops.
- Electrical efficiency can be doubled compared to combustion.
- Combustion pollution is eliminated.
- The technology is still in the R&D stage, but we are beginning to scale up.





Bio-Hydrogen

- H_2 has 2 e^- equivalents per mole.
 - $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$
- Its greatest energy value is when used as the fuel for electricity generation in a conventional fuel cell – combustionless, pollution-free electrical power.
- Also widely used for hydrogenations in the chemical and petrochemical industries.
- Today, the H_2 industry is large and mature.
- Economic value is 5- to 10-fold greater than CH_4 per electron equivalent.





Modifying the MFC to an MEC to Produce H₂

